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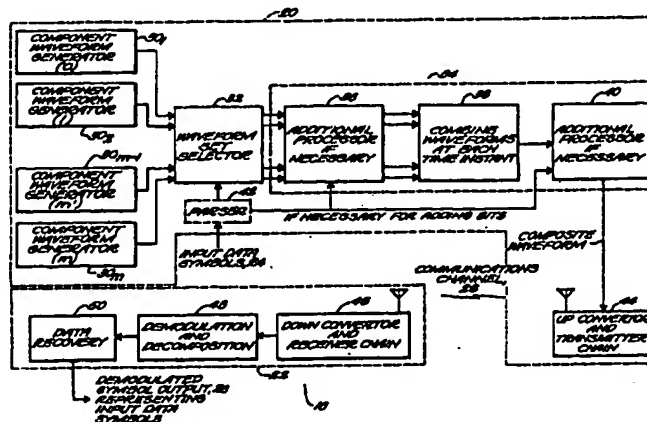
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International Bureau



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H04B 1/69, H04L 27/00, 27/20		A1	(11) International Publication Number: <b>WO 98/59428</b>
			(43) International Publication Date: 30 December 1998 (30.12.98)
(21) International Application Number: PCT/US98/12913		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).	
(22) International Filing Date: 22 June 1998 (22.06.98)		Published With international search report.	
(30) Priority Data: 60/050,511 23 June 1997 (23.06.97) US			
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(54) Title: WIRELESS COMMUNICATIONS SYSTEM FOR TRANSMITTING AND RECEIVING DATA WITH INCREASED DATA RATES AND ROBUSTNESS



(57) Abstract

A data communications system (18) for conveying a series of input data symbols includes a transmitter subsystem (20) and a receiver subsystem (22). The transmitter subsystem (20) generates a series of composite waveforms corresponding to a series of input data symbols by selecting (32) a set of mutually orthogonal component waveforms, then combines (36, 40) contemporaneous portions of at least two of the component waveforms so as to form a composite waveform which is unique to the data symbol. The transmitter subsystem (20) uses the composite waveform to modulate a carrier signal and transmit (44) the carrier signal over a communication channel (26). The receiver subsystem (22) receives the carrier signal and recovers the composite waveform from the carrier signal (46). The receiver subsystem identifies the data symbol by, at least in part, decomposing (48) the composite waveforms into their constituent component waveforms so as to identify which composite waveforms have been transmitted.

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**WIRELESS COMMUNICATIONS SYSTEM FOR TRANSMITTING AND  
RECEIVING DATA WITH INCREASED DATA RATES AND ROBUSTNESS**

1 **CROSS-REFERENCE TO RELATED APPLICATIONS**

2       This application is based on provisional application serial no. 60/050511 filed  
3 June 23, 1997, the prior application being incorporated herein by reference.

4

5 **STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH**

6       Not Applicable

7

8 **REFERENCE TO MICROFICHE APPENDIX**

9       Not Applicable

10

11 **FIELD OF THE INVENTION**

12       The present invention relates to data transmission systems, and more  
13 particularly, wireless data transmission systems which achieve high data transfer  
14 rates with robust performance.

15

16 **BACKGROUND OF THE INVENTION**

17       Generally, in transmitting digital information over a wireless communication  
18 channel, a data transmitter uses data transformation techniques for transforming a  
19 sequence of discrete information symbols representing the digital information into a  
20 continuous waveform on a carrier for transmission over the channel to a data  
21 receiver. The receiver reverses the transmit process using complementary techniques  
22 in order to recover the original information sequence. Often, the transmitter  
23 performs a sequence of sub-transformations during the transformation process,  
24 depending upon the synthesis approach employed. The synthesis approach, for  
25 example, comprises source encoding, error-control encoding, waveform generation,  
26 and frequency translation. For present, illustrative purposes, the overall transmitter  
27 process will be referred to as "modulation", and the receiver process will be referred  
28 to as "demodulation". Two goals of a communications system design is to effect this

1 modulation/demodulation for an intended communications channel with a high  
2 throughput of data, i.e., the transmission of data at a data transfer rate as high as  
3 possible within the bandwidth limitations imposed by the communications channel,  
4 and with an adequately low probability of corruption or loss of the information.

5 In many applications, the frequency bandwidth within which the data is  
6 transmitted is limited by government regulations (such as those imposed in the  
7 United States by the Federal Communications Commission, or FCC), so when  
8 designing a system emphasis is placed on transmitting data at higher data rates within  
9 the allotted band of frequencies. For example, when designing wireless computer  
10 networks, such as a local area network (LAN), the FCC currently has allocated about  
11 80 MHZ of bandwidth for local transmission and reception for unlicensed  
12 transmitters. If data occupies a relatively small bandwidth of frequencies (e.g., voice  
13 data would occupy 20 KHz worth of bandwidth), one can utilize the entire allocated  
14 bandwidth to widen the transmitted data (or spread the spectrum of the data) to make  
15 the transmission more robust. For some modulation techniques, more bandwidth  
16 allows for faster transmission of binary symbol data at faster rates. However, as the  
17 data rate of the binary symbols increases, multipath interference becomes more of a  
18 problem to the point where the faster data will become difficult if not  
19 incomprehensible to understand as the data is received at the receiver. Accordingly,  
20 designs often slow down the rate at which data is transmitted so that the data can be  
21 understood without concern of multipath interference.

22 In general, different values of input data to be transmitted can be thought of  
23 as respectively representing different symbols with the total number of possible  
24 symbols representing a signaling alphabet. Each data input symbol therefore can be  
25 represented by a unique waveform which can be transmitted through a transmission  
26 medium. By serially transmitting these waveforms (representing a series of data  
27 input symbols) one can transmit a message that conveys meaning. The waveform  
28 representing each symbol and transmitted through the medium thus must be uniquely  
29 recognizable, and must be selected from a set of possible unique waveforms used to  
30 represent the possible symbols of the signaling alphabet. The number of possible  
31 symbols in a signaling alphabet is referred to as the order of the alphabet. Thus, one

1 approach to increasing data transfer rates is to use a higher-order signaling alphabet  
2 to represent the input data with a corresponding number of unique waveforms for  
3 transmitting the information through the transmission medium.

4 A data transmitter capable of robustly transmitting data at high data rates by  
5 using a higher-order signaling alphabet is described in our prior application US  
6 Application Serial No. 08/369778 entitled a High-Data-Rate Wireless Local-Area  
7 Network filed December 30, 1994, and assigned to the present assignee (the  
8 "Pending Application"), which application is a continuation-in-part of US  
9 Application Serial No. 08/198,138, filed February 17, 1994, now abandoned. The  
10 Pending Application describes an improved data transmitter and receiver in which  
11 one preferred embodiment uses a direct sequence, spread spectrum (DSSS) signal  
12 format when communicating between the two devices. The preferred system uses  
13 unique digital waveforms forming a relatively high-order signaling alphabet to  
14 communicate between the two devices. These waveforms comprise a set of unique  
15 waveforms, which are mutually orthogonal with respect to one another. By using a  
16 set of 16 unique waveforms, for example, sixteen different symbols can be  
17 represented. Having a choice of one of 16 waveforms thus accounts for 4 binary bits  
18 for representing 16 different data input symbols since four bits, or  $2^4$ , has 16 possible  
19 values.

20 The result is to greatly increase the available data rates for wireless LANs  
21 while maintaining power efficiency and robustness in the presence of a multipath  
22 environment. This can be contrasted to prevailing "digital-radio" techniques  
23 employed on telephone microwave trunking links, which use Quadrature Amplitude  
24 Modulation (QAM), and which are very bandwidth efficient, but which are very  
25 power inefficient and would degrade terribly in multipath typical of LAN  
26 environments.

27 Accordingly, it is desirable to provide faster data rates while maintaining  
28 power efficiency with robustness in the presence of a multipath environment.

29

### 30 SUMMARY OF THE INVENTION

31 In accordance with one aspect of the present invention, a group of waveforms

1 for transmitting data through a transmission medium is provided. The waveforms of  
2 the group correspond, at least in part, to unique data symbols values, wherein each of  
3 the data symbols is represented, at least in part by a waveform, herein referred to as  
4 the composite waveform, derived as a function of:

5 (A) selecting K waveforms from a set of M mutually  
6 orthogonal component waveforms so as to produce K selected  
7 component waveforms for each of the data symbols, wherein  
8  $2 \leq K \leq M-1$ ; and

9 (B) processing contemporaneous portions of the K selected  
10 waveforms so as to produce, at least in part, the composite waveform  
11 representative of the symbol.

12 In accordance with one embodiment of the present invention, each of the  
13 composite waveforms is derived as a function of:

14 (A) grouping the M component waveforms into n subsets,  
15 each subset including m component waveforms;

16 (B) selecting at least one waveform from each subset of n  
17 subsets of the waveforms so as to produce K selected orthogonal  
18 component waveforms; and

19 (C) processing contemporaneous portions of the K selected  
20 orthogonal waveforms so as to produce the composite waveform  
21 representative of at least a part of the symbol.

22 In accordance with one embodiment of the present invention, the composite  
23 waveform is used to modulate a carrier signal so as to produce a modulated carrier  
24 signal for transmitting the composite waveform through the transmission medium. It  
25 is a further specific embodiment, the composite waveform is derived from two  
26 intermediate composite waveforms, which in turn are each at least in part derived  
27 from K selected waveforms, and the modulated carrier signal is produced as a  
28 function of:

29 (A) simultaneously transmitting the two intermediate  
30 composite waveforms respectively through an in-phase path and a  
31 quadrature path coupled to one another so as to produce a in-phase

1 modulated waveform and a quadrature modulated waveform, the two  
2 modulated waveforms being 90° out of phase with respect to one  
3 another; and

4 (B) combining the in-phase modulated waveform and the  
5 quadrature modulated waveform so as to produce a quadrature phase  
6 modulated carrier signal.

7 In accordance with another embodiment, the intermediate waveform from the  
8 in-phase path is encoded with a first spreading function, and the intermediate  
9 waveform from the quadrature path is encoded with a second spreading function.

10 As a further embodiment, the individual component waveforms can be  
11 selectively inverted so as to create a larger set of composite waveforms.

12 In another embodiment the component waveforms are selectively inverted  
13 using PSK techniques, while in another embodiment the waveforms are selectively  
14 inverted using DPSK techniques.

15 In still another embodiment, the orthogonal waveforms include Walsh  
16 functions.

17 In yet another embodiment, n and m each equal 4 so that the set of M  
18 waveforms includes four subsets, each having four of the Walsh functions. In  
19 another embodiment, n equals 2 and m equals 8 so that the set of M waveforms  
20 includes two subsets, each having eight of the Walsh functions.

21 In another embodiment, the waveforms are chosen so that the composite  
22 waveform is produced so as to have only two possible amplitude levels, and in  
23 another embodiment at least three possible amplitude levels.

24 As a further embodiment the composite waveform is multiplied by a  
25 spreading function, while in another embodiment, each of the K selected component  
26 waveforms is multiplied by a spreading function so as to produce K spread  
27 waveforms, prior to producing the composite waveform.

28 In accordance with another aspect of the present invention, a data  
29 communications system for and method of transferring data as predefined data  
30 symbols of the symbol alphabet are provided using composite waveforms generated  
31 in accordance with the teachings provided herein. The data communications system



1 includes a transmitter subsystem and a receiver subsystem. The transmitter  
2 subsystem and receiver subsystem are equipped so as to respectively provide  
3 encoded composite waveforms so that the data can be transmitted through the  
4 medium, and decode the composite waveforms so that the data can be retrieved.  
5 Alternative embodiments of the transmitter subsystem and or receiver subsystem  
6 utilize the various embodiments of the method and systems described herein.

## 7 8 BRIEF DESCRIPTION OF THE DRAWINGS

9 The foregoing and other objects of this invention, the various features thereof,  
10 as well as the invention itself, may be more fully understood from the following  
11 description, when read together with the accompanying drawings in which:

12 Fig. 1 shows a simplified block diagram of one embodiment of a data  
13 communications system designed in accordance with the present invention;

14 Fig. 2 is a simplified block diagram of another embodiment of a data  
15 communications system designed in accordance with the present invention;

16 Fig. 3 illustrates an exemplary case of the differential inversion technique of  
17 conveying an additional bit of information;

18 Fig. 4 illustrates a linear summation of four representative Walsh functions to  
19 produce a multilevel component signal;

20 Fig. 5 is a simplified block diagram of another embodiment of a transmitter  
21 subsystem of a data communications system and using DPSK and PN coding  
22 techniques;

23 Fig. 6 is a simplified block diagram of another embodiment of a transmitter  
24 subsystem of a data communications system using PSK and PN coding techniques;

25 Fig. 7 is a simplified block diagram of another embodiment of a transmitter  
26 subsystem of a data communications system using quadrature phase modulation to  
27 increase the number of bits/symbol;

28 Fig. 8 is a simplified block diagram of another embodiment of a receiver  
29 subsystem of a data communications system using PSK, PN and quadrature phase  
30 modulation coding and demodulation decoding techniques;

31 Fig. 9 is a simplified block diagram of another embodiment of a receiver

1 subsystem of a data communications system using PSK and PN modulation coding  
2 and demodulation decoding techniques; and

3 Fig. 10 is a simplified block diagram of another embodiment of a receiver  
4 subsystem of a data communications system using DPSK and PN coding techniques.

## 5 6 DETAILED DESCRIPTION OF THE INVENTION

7 In the drawings the same numerals are used to refer to like or equivalent  
8 parts, and are provided for ease of exposition. Such references numerals are not  
9 intended to limit the invention as defined by the appended claims.

10 The invention is directed to a system for and method of achieving what is  
11 considered to be very high data rates through a communications channel such as a  
12 radio link, while still maintaining (a) high processing gain against multipath and  
13 interference, and (b) low symbol rates for protection against inter-symbol  
14 interference.

15 More specifically, in accordance with one aspect of the invention, the  
16 transmitter of the present invention includes a waveform generator that creates any  
17 one of a plurality of unique composite waveforms, each generated as a function of a  
18 plurality of unique, predefined component waveforms, each composite waveform (a)  
19 including  $K$  component waveforms selected from a waveform set of size  $M$ , wherein  
20  $2 \leq K \leq M-1$ ; and (b) representing, at least in part, one of the data input symbols. A  
21 unique aspect of this invention is the composite waveform generation from the  
22 predefined combinations of component waveforms. Each component waveform is  
23 created by simultaneously combining the chosen mutually-orthogonal component  
24 waveform functions. The combination of component waveform functions chosen for  
25 each composite waveform is unique with respect to the others so that the resulting  
26 composite waveform can be recognized as representing, at least in part, a  
27 corresponding data input symbol. As will be evident hereinafter, in accordance with  
28 one embodiment of the invention, the composite envelope is multi-level; while in  
29 accordance with another embodiment of the invention the possible mutually-  
30 orthogonal component waveforms that are combined for each possible composite  
31 waveform are chosen so that the envelope is always binary-level. These methods of

1 generation assures high performance while transmitting a large number of  
 2 bits/symbol, and allows a simple method of demodulation to be used. The carrier  
 3 modulation means has sufficient dynamic range to support a linear transfer of the  
 4 modulation to the carrier signal.

5 The foregoing may be better understood by the following: when only one of  
 6 M mutually orthogonal waveforms is selected for transmission of each symbol bit as  
 7 is described in the Pending Application,  $\log_2 M$  bits of information are transmitted. If  
 8 a predefined combination of K waveforms are transmitted simultaneously, then the  
 9 number of bits transmitted is increased to:

$$10 \quad \log_2 \frac{M!}{K!(M-K)!} \quad (1)$$

11 bits of information per symbol. For example, if M=16 and K=2, then 6.9 bits/symbol  
 12 are provided; while simultaneously sending 3 of 16 gives 9.1 bits/symbol. This  
 13 offers higher data rates, but progressively incurs amplitude fluctuation and  
 14 transmitted power increased by a factor of K. This modulation technique is  
 15 hereinafter referred to as "K/M-Orthogonal", read "K of M Orthogonal", where in  
 16 accordance with one aspect of the present invention  $2 \leq K \leq M-1$ . In order to exploit  
 17 K/M-Orthogonal signaling it is necessary to develop an effective coding scheme for  
 18 handling the fractional bit/symbol. Alternatively, one could round down the number  
 19 of bits/symbol and use this to find a very simple encoding scheme. For example, for  
 20 2/16-Orthogonal exploiting 6 bits/symbol, the encoding could comprise two  
 21 independent groupings of 8 mutually orthogonal functions in which picking 1 of 8  
 22 provided 3 bits from each symbol. (This is equivalent to 8/16-Orthogonal).

23 In general, the receiver of the present invention, recognizes the composite  
 24 waveform as unique by recognizing the individual component waveforms so that the  
 25 corresponding input data symbol can be identified.

26 Fig. 1 shows a simplified block diagram of one embodiment of a data  
 27 communications system 18 in accordance with the present invention. This  
 28 embodiment of the invention includes a transmitter subsystem 20 and a receiver  
 29 subsystem 22. In general, the transmitter subsystem 20 receives a series of input data  
 30 symbols at 24, generates composite waveforms representative the input data symbols,

1 as a function of the K/M-orthogonal signaling technique, encodes the generated  
2 composite waveforms onto a carrier signal and transmits the carrier signal via a  
3 communications channel 26. The receiver subsystem 22 receives the carrier signal  
4 via the communications channel 26, decodes the composite waveforms from the  
5 carrier signal and produces decoded data symbols (which are a reproduction of the  
6 input data symbols) as output data elements 28.

7 More specifically, as shown in Fig. 1, the transmitted subsystem includes M  
8 different waveform generators 30 for respectively generating M mutually orthogonal  
9 signal waveforms. The waveforms are preferably Walsh function waveforms. With  
10 Walsh function waveforms, the outputs of the generators are each in the form of a  
11 binary waveform that proceeds in time. The outputs of the generators are all  
12 connected to the input of a waveform selector 32. The waveform selector 32 is  
13 responsible for determining how the waveforms are selected for each generated  
14 composite waveform. The selector 32 chooses a subset K of the M waveforms,  
15 wherein  $2 \leq K \leq M-1$  based upon the instructions it receives from the portion the input  
16 data symbols 24 to be represented by the selected waveforms. One criterion of the  
17 selector, which will become more evident hereinafter, is that the possible  
18 combinations of K waveforms are all uniquely identifiable with respect to one  
19 another. In other words, there can be no repetition of subsets of the waveforms. For  
20 example, if  $K=2$  and  $M=3$ , the possible selections for waveform sets are (3,2), (3,1),  
21 (3,0), (2,1), (2,0) and (1,0). Waveform sets (3,2) and (2,3), for example, are consider  
22 repetitious. Thus, in the example, there are six possible choices resulting in six  
23 possible outputs from the selector 32. The output waveforms selected by selector 32  
24 are processed by the modular and processor 34. The latter preferably includes the  
25 signal combiner 36 for simultaneously combining the selected waveforms appearing  
26 at the outputs of the selector 32, resulting in at least a two level composite waveform.  
27 The combiner 36 preferably sums the waveforms in a linear fashion, however, the  
28 summations may be in accordance with other linear or non-linear functions. This  
29 composite waveform in the example given will be one of six possible and unique  
30 waveform symbols. The six possible composite waveforms results in less than 3 bits  
31 per symbol.

1           As will be more evident hereinafter, the modulator and processor 34 of the  
2 transmitter subsystem, preferably although not necessarily, also comprises either or  
3 both: means 38, coupled to each output of the waveform selector, for further  
4 processing each individual waveform, and/or means 40, coupled to the output of the  
5 summer 36, for further processing the composite signal output of the signal summer  
6 36. Means 38 can be used, for example, to encode each of the individual outputs of  
7 the selector 32 with a separate coding signal, such as a spreading function, e.g., a PN  
8 code, independent of the data stream, for providing privacy as well as processing gain  
9 against another transmitter with the same data modulation, and assuring minimum  
10 modulation bandwidth properties. A similar result can occur if the output composite  
11 waveform from the summer 36 is modulated with a spreading function by the means  
12 40.

13           Also evident hereinafter, is the fact that the means 38 and 40 can also be used  
14 to encode additional bits on each modulated output waveform of the transmitter  
15 subsystem, as will be evident hereinafter. Accordingly, in this latter instance, a  
16 parser is used to provide at least the relevant portions of the input data symbols 26 to  
17 the means 38 and 40 so that the proper values of the generated waveform symbols are  
18 generated through channel 26. For example, in accordance with yet another  
19 embodiment of the present invention, an additional bit is added using signal phase to  
20 K/M-Orthogonal to make K/M-Bi-Orthogonal. For example, for  $M=16$  and  $K=2$ ,  
21 K/M-Bi-Orthogonal provides 8.9 bits/symbol. By adding an additional bit using  
22 signal phase, the number of bits/symbol is increased to 9.9 bits/symbol. There are  
23 also both coherent and non-coherent implementations of K/M-Bi-Orthogonal. In  
24 addition, additional bits can be added by selectively inverting each of the component  
25 waveforms to make composite waveforms. This can be accomplished, for example,  
26 using PSK and DPSK modulation techniques. All of these modifications will be  
27 more evident hereinafter.

28           As illustrated in Fig. 1, once modulated, the modulated composite signal may  
29 then be upconverted, amplified and transmitted by the up converter and transmit  
30 chain 44 so that the modulated signal can be transmitted through channel 28. For  
31 example, the composite waveform output of the modulator and processor 34 can be

1     used to modulate a carrier signal so as to produce a modulated composite signal for  
2     transmission over the transmission channel 26.

3             Upon reception by the receiver subsystem 22, the modulated composite signal  
4     is down converted and processed through the receive chain, generally indicated at 46,  
5     and subsequently applied to the demodulator 48. The latter demodulates and/or  
6     decompositions the received signal all in a manner complementary to the process of  
7     the transmitter subsystem 20, as will more evident hereinafter. Demodulation  
8     includes the process of removing the carrier signal, and processing the received  
9     composite waveform signal. If a separate coding, such as a spreading function, e.g.,  
10    PN coding, is used in the transmitter subsystem, then the signal is decoded to remove  
11    the spreading function code. The K component waveforms present in the received  
12    composite waveform can then be determined, for example, using well known  
13    correlation techniques, as will be discussed in greater detail hereinafter. In addition,  
14    techniques used to encode the transmitted symbol with additional bits can be  
15    decoded. The data symbols 24 can then be recovered as indicated at 50 and provided  
16    as the output 28.

17            In one embodiment of the invention, it is possible to separate the basis  
18    functions into orthogonal subgroups. For example, instead of sending 8.9 bits per  
19    symbol by transmitting any 2 of 16 waveforms, it is possible to send waveforms  
20    representing 6 bits per symbol by transmitting one waveform from each of 2 groups  
21    of 8 waveforms, or 8 bits per symbol by transmitting one waveform from each of 4  
22    groups of 4. These become even more attractive if Bi-Orthogonal signaling is  
23    considered. One could send waveforms representing 10 bits per symbol by using 4-  
24    ary Bi-Orthogonal on 4 subgroups of 16 basis functions. Progressively, more  
25    amplitude fluctuations are incurred as more subgroups are employed, and the average  
26    power required is proportional to the number of subgroups (a factor of  $M/N$ , or 3 dB  
27    per splitting). This can be called "N subdivided M-Orthogonal" signaling, using the  
28    notation  $N(M)$ -Orthogonal, where N-Orthogonal is used in  $M/N$  basis functions  
29    (hence M is the total number of basis functions). This has an obvious extension to  
30    multiple waveforms (e.g.,  $K/N(M)$ -Orthogonal) as well as to Bi-Orthogonal variants.

31            M-Orthogonal (or Bi-Orthogonal) waveforms can be used with either

1 coherent or non-coherent receiver subsystems; that is, the receiver subsystem might  
2 make use of a locally generated coherent reference local oscillator, or it might  
3 employ processing appropriate for accommodating the unknown carrier phase at the  
4 receiver. In either case, the modulation at the transmitter is, by implication,  
5 impressed upon the carrier as a single baseband channel. However, coherent  
6 receivers rotate the phase of the local oscillator so that it appears to be in-phase with  
7 the received signal carrier; the quadrature component of the carrier contains noise  
8 only. It is clearly possible to place independent information on the quadrature  
9 carrier, thus enabling a factor of two increase (i.e., doubling) in data rate. Clearly, if  
10 coherent reception can be effected this factor of two can also be applied to M-  
11 Orthogonal, M-Antipodal, and other variant-orthogonal modulations as well.

12 These and other modifications will be more apparent hereinafter.

13 For example, in Fig. 2 an exemplary embodiment is shown in which the basis  
14 waveform functions are separated into subgroups. In this embodiment, the  
15 embodiment of Fig. 1 is modified so that the set of mutually orthogonal signaling  
16 component waveforms generated by the generators (generally indicated at 110) are  
17 organized so as to include  $n$  subsets 112, each of  $m$  predetermined waveforms. In  
18 addition, a separate selector 114 is provided for each subset 112. For each input data  
19 symbol, each selector 114 selects at least one component waveform from the  
20 corresponding subsets 112 as a function of the input data symbols 24 so as to produce  
21  $K$  selected component waveforms. In the illustrated embodiment, where one  
22 waveform is selected from each subgroup  $K=n$ . However, where, for example, two  
23 waveforms are selected from each subgroup,  $K=2n$ ; selecting three waveforms from  
24 each subgroup results in  $K=3n$ , and so on.

25 Thus, by way of example, in Fig. 2 assume the set of mutually orthogonal  
26 waveforms includes 16 Walsh functions, subdivided into four subsets of four. In this  
27 embodiment, each selector 114 selects one Walsh function from each of the four  
28 groups as a function of at least one of the selected data elements, to produce a  
29 selected set of four Walsh functions. Four sets of four waveforms allows  $4^4 = 256$   
30 possible combinations of one selection from each subset, so each selection of four  
31 waveforms from the waveform set can convey 8 bits of information. This is true

1 because each set of four selected waveforms represents one symbol from an alphabet  
2 size of  $256 = 2^{12}$ . Equivalently stated, each subgroup produces a waveform which  
3 represents one symbol from an alphabet size of  $4 = 2^2$ , conveying 2 bits of  
4 information. Four subgroups together convey  $4 \cdot 2 = 8$  bits of information. In this  
5 instance,  $K=n$ . It should be noted that more than one waveform can be selected from  
6 each subgroup, in which case  $K$  equals a multiple of  $n$ .

7 As previously stated, the number of waveforms transmitted can be increased  
8 by a factor of two (by an additional bit) by using signal phase. In one such  
9 embodiment of the invention, the size of each of the subsets is increased by a factor  
10 of two by including the inverse or phase version of each of the Walsh functions. In  
11 the given example, four sets of eight waveforms allows  $8^4 = 4096$  possible  
12 combinations of one selection from each subset, so each selection of four waveforms  
13 can convey 12 bits of information. Equivalently stated, each subset produces a  
14 waveform which represents one symbol from an alphabet size of  $4 = 2^3$ , conveying 3  
15 bits of information. Four subsets together convey  $4 \cdot 3 = 12$  bits of information.

16 In yet another embodiment of the invention, the extra bit per subset is  
17 conveyed by inverting or not inverting the selected waveform from each of four  
18 subsets of four prior to being combined by the modulator and processor 34. In the  
19 example given, this is equivalent to the aforementioned four subsets 112 of eight  
20 Walsh functions, without having to store eight Walsh functions per subset 112 or  
21 having to incorporate means for generating eight Walsh functions per subset 112.  
22 Selected inversion can be accomplished, for example, using PSK and DPSK  
23 encoding techniques.

24 Fig. 3 illustrates an exemplary case of the differential inversion technique of  
25 conveying an additional bit of information which can be used in both the Fig. 1 and  
26 Fig. 2 embodiments. The subgroup is shown to include four Walsh functions in the  
27 non-inverted section designated  $W_0$ ,  $W_1$ ,  $W_2$  and  $W_3$ . The Walsh functions in the  
28 inverted section are designated  $\bar{W}_0$ ,  $\bar{W}_1$ ,  $\bar{W}_2$  and  $\bar{W}_3$ . In this example, the first two  
29 bits of the data conveyed is carried by the Walsh function itself, and the third bit is  
30 conveyed by the relationship between the adjacent functions. In Fig. 3, the first  
31 three-bit character has an "X" in the third place because the previous character is not



1 given, and so the third bit cannot be determined. Such a differential inversion  
2 technique allows the use of a non-coherent receiver; i.e., one which does not need to  
3 distinguish between a particular Walsh function and its inverted version in order to  
4 extract the additional bit of information.

5 In general, as previously mentioned the modulator and processor 34 includes  
6 a linear or non-linear function which combines contemporaneous portions of the  
7 selected waveforms to produce a composite waveform. In one form of the invention,  
8 the modulator and processor 34 includes linear summing means for summing  
9 contemporaneous portions of the  $n$  selected waveforms. Such summing means is  
10 generally characterized by a continuous operator; i.e., one which continuously sums  
11 along all of the selected waveforms. However, those skilled in the art will recognize  
12 that a discrete summer may also be used; i.e., one which treats the selected  
13 waveforms as collections of discrete samples, wherein contemporaneous samples  
14 from the selected waveforms are summed to produce a composite waveform made up  
15 of a series of discrete samples. In one embodiment of the invention, the modulator  
16 and processor 34 receives the four selected Walsh functions as digital waveforms;  
17 i.e., waveforms represented by either a zero or a one, and a digital zero state is treated  
18 as a +1 amplitude for summation, and a digital one state is treated as a -1 amplitude  
19 for summation. Fig. 4 illustrates a linear summation produced by this embodiment  
20 for four representative Walsh functions. In the illustrated case, the composite  
21 waveform has a multi-level amplitude with possible values of +4, +2, 0, -2 and -4.

22 In accordance with another embodiment of the invention, the possible  
23 combinations of waveforms can be predefined and limited so that any possible  
24 combined signal will remain bi-level, e.g., +1 and -1. Where, for example, four  
25 subsets, each of four standard Walsh functions are used, and by using phase inverted  
26 waveforms to double the number of bits/symbol, the restricted waveforms will be  
27 limited to three waveforms, a combination of two Walsh functions and one for phase.  
28 This has the effect of reducing the number of bits/symbol from 12 to 9, but allows for  
29 more efficient use of the power amplifier for transmitting the transmitted signal since  
30 the modulated transmitted signal will have a constant envelope, irrespective of sign,  
31 and the power amplifier can be driven between saturated and off states (for the two

1 values). Decreasing the number of bits/symbol from 12 to 9 provides a decrease in  
2 throughput to one-quarter of the throughput using the 12 bits/symbol multi-level  
3 approach, but the number of waveforms used to provide the constant envelope  
4 modulated output is only one-eighth of the number of waveforms in the 12  
5 bit/symbol multi-level approach; in some applications a good tradeoff.

6 As previously described, in another embodiment of the invention a pseudo-  
7 random noise (hereinafter referred to as "PN") modulation is added to the waveforms  
8 after the selected waveforms have been combined, although those skilled in the art  
9 will realize that because of the linear associative property, the PN modulation may be  
10 added prior to the combination as long as the modulator and processor 34 includes a  
11 linear function which combines contemporaneous portions of the selected waveforms  
12 to produce a composite waveform (e.g., linear summation), rather than a non-linear  
13 function. The latter is shown, for example in Figs. 5, 6 and 7, wherein exclusive OR  
14 gates 120 are used to add a binary PN code to each output of each selector 114. PN  
15 modulation provides processing gain against an interfering signal with the same or  
16 similar data modulation properties and assures minimum modulation bandwidth  
17 characteristics of the carrier transmitted by the invention. Because the PN code is  
18 pseudo-random and the ratio of the orthogonal waveform length to the smallest PN  
19 chipping rate is large, two identical waveforms with different PN overlays are for all  
20 practical purposes orthogonal and therefore distinguishable from one another.

21 As previously described, additional bits can be encoded in the composite  
22 waveform by selectively inverting each of the component waveforms to create a  
23 larger set of component waveforms to make the composite waveforms. Thus, in still  
24 another embodiment of the invention, also illustrated by way of example in Fig. 5, an  
25 additional bit per subgroup can be encoded in the composite waveform by a  
26 differential inversion technique similar to Differential Phase Shift Keying  
27 (hereinafter referred to as "DPSK"). In the example shown, the waveforms produced  
28 by each subset of waveform generators 112 include four Walsh functions. By  
29 providing the output(s) of each output of each selector(s) 114 to the input of an  
30 exclusive OR gate 122, a DPSK modulation signal can be provided to the output  
31 waveforms of the selectors so that the gate provides either the waveform output of the

1 corresponding selector, or the inverse of the waveform. In the example, the  
2 waveforms provided by the selectors and their inverse forms therefore provide a total  
3 of eight waveforms per subset 112. However, with the differential inversion  
4 technique, selecting a particular function or its inverse only conveys two bits of  
5 information. An additional bit is conveyed by the relationship between the current  
6 waveform and the previous waveform. Each subset may be viewed as having an  
7 inverted section and a non-inverted section. In general, if the current and previous  
8 waveforms are selected from the same section (either both inverted or both non-  
9 inverted), one sense of the bit is conveyed (e.g., a digital zero). If the current and  
10 previous waveforms are selected from different sections, the other sense of the bit is  
11 assumed (e.g., a digital one).

12 It should be appreciated that in addition to DPSK, other modulation  
13 techniques can be used to address one or more bits/symbol. For example, in another  
14 embodiment shown in Fig. 6, the carrier modulation includes phase shift keying  
15 (hereinafter referred to as PSK). In this embodiment exclusive OR gates 112 are used  
16 to modulate each output waveform of each selector 114 with a PSK modulation  
17 signal. It should be appreciated that alternatively the PSK modulation signal can be  
18 applied to the output of the signal summer 36.

19 As previously described other techniques can be used to encode additional  
20 data within each composite waveform. For example, in accordance with another  
21 embodiment of the invention, shown in Fig. 7, additional data can be simultaneously  
22 transmitted with modulator 130, which can be used for modulating the quadrature  
23 component of the carrier signal with one intermediate composite waveform, and the  
24 in-phase component of the carrier with another intermediate composite waveform,  
25 thus sending data via two different, independent carrier phases. In such a system, the  
26 receiver element is coherent, i.e., it recovers information regarding the received  
27 carrier signal's phase, and so it can distinguish between the in-phase and quadrature  
28 components of the signal. As shown in Fig. 7, the waveforms modulated on each  
29 phase of the carrier also may, although not necessarily, be overlaid with independent  
30 PN codes, with the use, for example, of exclusive OR gates 120, to add processing  
31 gain to one carrier phase against the signal on the other carrier phase when the

1 receiver has imperfect phase alignment with the transmitter. The embodiment may  
2 also use other modulation techniques as previously described, wherein, for example,  
3 PSK modulation is shown in the Fig. 7 embodiment. In the example given wherein  
4  $n=4$  and  $m=4$ , the composite waveform can convey 12 bits of information (one  
5 selected waveform per group of four waveforms gives two bits per group; four groups  
6 gives eight bits; a set of inverted waveforms for each of four groups gives extra bit  
7 per group for a total of 12 bits), sending data via two phases of the carrier provides a  
8 throughput of 24 bits per composite waveform period.

9 In Fig. 7 the set of waveforms provided by the waveform generators are  
10 represented by "n" subsets of Walsh generators, each subset for generating "m"  
11 unique waveforms, where n represents the subset index and m represents the  
12 waveform index within the  $n^{\text{th}}$  subset. Where  $n=4$  and  $m=4$ , a set of eight waveform  
13 selectors 114 are provided. The symbol parser 42 provides instructions to the  
14 selectors as well as to two sets of exclusive-or gates 122. A pair of waveform  
15 combiners 36 combine the four received waveforms. The modulator 130 is  
16 represented as a quadrature phase shift keying (hereinafter referred to as "QPSK")  
17 modulator 130, the output of which is connected to a transmitter represented as a  
18 transmit block and an antenna 132. It should be appreciated that the embodiment  
19 shown in Fig. 7, can be modified to use DPSK combined with in-phase and  
20 quadrature modulation techniques to encode the resulting composite waveform with  
21 twice as many bits/symbol than provided by the Fig. 5 embodiment. The transmit  
22 block may include such radio frequency (hereinafter referred to as RF) front end  
23 components as an amplifier, an up-converter and a spectrum-shaping filter, but those  
24 skilled in the art will realize that alternate transmitter architectures may be used.

25 It should be appreciated that the embodiments described in connection with  
26 Fig. 5, 6 and 7 are described in connection with the Fig. 2 embodiment wherein n  
27 subsets are used, the additional encoding techniques can also be applied to the Fig. 1  
28 embodiment, i.e., K of M waveforms.

29 Fig. 8 shows a block diagram of a preferred embodiment of the receiver  
30 subsystem useful with and is the complement to the Fig. 7 transmitter subsystem.  
31 The receiver subsystem includes an antenna and a receive chain 198. The receive

1 chain may include such RF components as a receive filter, a low noise amplifier and  
2 a down converter, although those skilled in the art will recognize that other receiver  
3 front end architectures may be used. The receive chain couples the propagating  
4 transmission signal from the communications channel to produce a received carrier  
5 signal. A demodulator 200 receives the received carrier signal to recover the  
6 composite waveform embedded in the carrier signal by the transmitter subsystem.  
7 The demodulator 200 of the illustrated embodiment is a quadrature demodulator  
8 known to those skilled in the art, including a signal splitter 202, a pair of RF mixers  
9 204, a local oscillator (hereinafter referred to as "LO") 206, and a signal phase shifter  
10 208 to provide a quadrature version of the LO signal. One of the mixers mixes the  
11 carrier signal with the LO signal to produce an in-phase demodulated signal channel,  
12 and one of the mixers mixes the carrier with the quadrature version of the LO signal  
13 to produce a quadrature demodulated signal channel.

14 A decompositioner, indicated generally as 210, includes analog to digital  
15 converters (ADCs) 212, for respectively digitizing the in-phase demodulated signal to  
16 produce a sampled in-phase signal and the quadrature demodulated signal to produce  
17 a sampled quadrature signal. The two sampled signals are phase-adjusted via a  
18 coarse phase adjuster 214 based on the phase of the signals sensed by the sensor 216  
19 during a preamble in the transmitted waveform such that the processing in the  
20 correlators 222 are as if the LO were phase-aligned with the in-phase path. Only a  
21 coarse adjustment is necessary because the in-phase and quadrature path signals have  
22 different PN overlays, and the processing gain afforded by the PN overlay on one  
23 path will mitigate crosstalk from the other path due to imperfect phase alignment.  
24 The amount of coarse adjustment is that which is normally provided with typical  
25 QPSK demodulation. Following coarse phase adjustment, the decompositioner 210  
26 strips the proper PN code from the corresponding path with the exclusive OR gates  
27 218 and 220. In the illustrated embodiment gates 218 and 220 are used to serially  
28 multiply each of the sampled signal streams by the proper PN code, although those  
29 skilled in the art will realize that other methods of PN stripping may be used, such as  
30 parallel multiplication of a section of the sampled signal stream by the entire PN  
31 code. After the PN has been stripped from each of the sampled signal streams, each

1 stream is correlated against all of the Walsh functions in the four subsets using the  
2 correlators 222, since  $n=4$  in the example.. The correlators 222 of decomposer  
3 210 identify the Walsh function producing the highest correlation value from each of  
4 the four subsets and outputs the Walsh function designation corresponding to this  
5 identification as indicated at 224. The decomposer 210 also provides PSK  
6 demodulation and determines at blocks 224 whether the identified Walsh function is  
7 from the same waveform section (i.e., either both inverted or both non-inverted) or  
8 from the opposite waveform section (i.e., one from the inverted section and one from  
9 the non-inverted section) with respect to the previous waveform, and extracts an  
10 additional bit from this relationship as defined herein and as indicated at 226. The  
11 data recoverer 50 includes a symbol assembler 228 which receives the Walsh  
12 function designations and the adjacent waveform relationship information from the  
13 decomposer 210 and produces a series of output data elements 28. The data  
14 recoverer 50 utilizes the same data element-to-Walsh function relationship employed  
15 by the selector 114 of the transmitter subsystem in order to produce the output data  
16 elements 28. Although the embodiment shown in Fig. 8 is illustrated as useful in  
17 decomposing waveforms provided as four subsets, each of four waveforms, the  
18 numbers can clearly vary.

19 In Fig. 9, the embodiment of Fig. 8 is modified to process PSK encoded  
20 signals transmitted, for example by a transmit subsystem such as the one shown in  
21 Fig. 6. Note that the demodulator 200 is modified as indicated at 230, to process only  
22 one composite waveform since the quadrature phase modulation is not used. In this  
23 embodiment, the splitter 202, the phase shifter 208 and one mixer 204 is eliminated.

24 Finally, in Fig. 10, an embodiment of a receiver is illustrated which can be  
25 used to demodulate 4 subsets of 4 with DPSK resulting in 12 bits per symbol,  
26 although these numbers can clearly vary. The Fig. 9 embodiment can be used, for  
27 example, to complement the transmitter subsystem shown in Fig. 5, and is similar to  
28 the Fig. 8 embodiment, except that only one PN code is stripped from the output of  
29 the converters 212, and the DPSK demodulation is provided at 230, to identify the  
30 relationship between the current and previous waveforms for each subset. The phase  
31 sensor 216 and coarse phase adjuster 214 is not necessary. Thus the greatest

1     magnitude from among the four in each subset will correspond to the transmitted  
2     waveform for that group. The bipolar in-phase and quadrature-phase correlator  
3     outputs for the greatest amplitude output will be used in the complex multiply for the  
4     DPSK demodulation. Those values will also be stored as the reference value for the  
5     DPSK of the next symbol.

6             The data communications system thus described provides a highly reliable,  
7     data communications system providing fast data rates while maintaining power  
8     efficiency with robustness in the presence of a multipath environment.

9             The invention may be embodied in other specific forms without departing  
10    from the spirit or essential characteristics thereof. The present embodiments are  
11    therefore to be considered in all respects as illustrative and not restrictive, the scope  
12    of the invention being indicated by the appended claims rather than by the foregoing  
13    description, and all changes which come within the meaning and range of the  
14    equivalency of the claims are therefore intended to be embraced therein.

What is claimed is

1           1.     A method of generating a group of unique composite waveforms  
2     corresponding to input data symbols for transmitting data represented by the symbols  
3     through a transmission medium, wherein each of the composite waveforms is derived  
4     as a function of:

5                 (A) selecting K waveforms from a set of M mutually orthogonal  
6     component waveforms so as to produce K selected component waveforms for  
7     each of the data symbols, wherein  $2 \leq K \leq M-1$ ; and

8                 (B) processing contemporaneous portions of the K selected waveforms  
9     so as to produce, at least in part, the composite waveform representative of  
10    the symbol.

1           2.     A method according to claim 1, wherein each of the composite  
2     waveforms is derived as a function of:

3                 (A) grouping the M component waveforms into n subsets, each subset  
4     including m component waveforms;

5                 (B) selecting at least one waveform from each subset of n subsets of  
6     said waveforms so as to produce K selected orthogonal component  
7     waveforms; and

8                 (C) processing contemporaneous portions of said K selected  
9     orthogonal waveforms so as to produce the composite waveform  
10    representative of at least a part of the symbol.

1           3.     A method according to claim 2, wherein said composite waveform is  
2     used to modulate a carrier signal so as to produce a modulated carrier signal for  
3     transmitting the composite waveform through the transmission medium.

1           4.     A method according to claim 3, wherein said composite waveform is  
2     derived from two intermediate composite waveforms, which in turn are each at least  
3     in part derived from K selected waveforms, and the modulated carrier signal is



4 produced as a function of:  
5 (A) simultaneously transmitting the two intermediate composite waveforms  
6 respectively through an in-phase path and a quadrature path coupled to one another so  
7 as to produce a in-phase modulated waveform and a quadrature modulated waveform,  
8 the two modulated waveforms being 90° out of phase with respect to one another,  
9 and  
10 (B) combining the in-phase modulated waveform and the quadrature  
11 modulated waveform so as to produce a quadrature phase modulated carrier signal.

1 5. A method according to claim 4, wherein the intermediate waveform  
2 from said in-phase path is encoded with a first spreading function, and the  
3 intermediate waveform from the quadrature path is encoded with a second spreading  
4 function.

1 6. A method according to claim 4, wherein the individual component  
2 waveforms can be selectively inverted so as to create a larger set of composite  
3 waveforms.

1 7. A method according to claim 2, wherein said composite waveform is  
2 derived from two intermediate composite waveforms, which in turn are each at least  
3 in part derived from K selected waveforms, and the individual component waveforms  
4 can be selectively inverted so as to create a larger set of composite waveforms.

1 8. A method according to claim 7, wherein the waveforms are selectively  
2 inverted using PSK techniques.

1 9. A method according to claim 7, wherein the waveforms are selectively  
2 inverted using DPSK techniques.

1 10. A method according to claim 2, wherein said orthogonal waveforms  
2 include Walsh functions.

1           11.    A method according to claim 10, wherein n and m each equal 4 so that  
2   said set of M waveforms includes four subsets, each having four of said Walsh  
3   functions.

1           12.    A method according to claim 10, wherein n equals 2 and m equals 8 so  
2   that said set of M waveforms includes two subsets, each having eight of said Walsh  
3   functions.

1           13.    A method according to claim 1, wherein the waveforms are chosen so  
2   that the composite waveform is produced so as to have only two possible amplitude  
3   levels.

1           14.    A method according to claim 1, wherein the waveforms are chosen so  
2   that the composite waveform is produced so as to have at least three possible  
3   amplitude levels.

1           15.    A method according to claim 1, wherein said composite waveform is  
2   multiplied by a spreading function.

1           16.    A method according to claim 1, wherein each of said K selected  
2   component waveforms is multiplied by a spreading function so as to produce K  
3   spread waveforms, prior to producing said composite waveform.

1           17.    A data communications system for transferring composite waveforms,  
2   representing at least in part a series of input data symbols, through a transmission  
3   medium, said system comprising:

4           (a) generating means for generating each component waveform of a set of M  
5   mutually orthogonal component waveforms;

6           (b) selection means for selecting, as a function of each of said data symbols, a  
7   predetermined number (K) of said component waveforms so as to produce K selected  
8   component waveforms for each of said data symbols, wherein  $2 \leq K \leq M-1$ ; and

9 (c) processing means for producing a composite waveform as a function of  
10 the combined contemporaneous portions of said K selected component waveforms.

1 18. A data communications system according to claim 17, wherein  
2 said generating means for generating each component waveform includes  
3 means for generating a group of at least n subsets of said waveforms, wherein each  
4 subset includes m component waveforms;  
5 said selection means includes means for selecting, as a function of each of  
6 said data symbols, at least one waveform from each of said n subsets of waveforms  
7 so as to produce K selected component waveforms corresponding to a respective one  
8 of said data symbols; and  
9 said processing means includes means for processing contemporaneous  
10 portions of said K selected waveforms so as to produce said composite waveform.

1 19. A data communications system according to claim 18, further  
2 including modulating means for modulating a carrier signal as a function of said  
3 composite waveform so as to produce a modulated carrier composite signal and  
4 transmission means for transmitting said modulated carrier composite signal through  
5 said transmission medium.

1 20. A data communications system according to claim 19,  
2 wherein said composite waveform is derived from two intermediate  
3 composite waveforms, which in turn are each at least in part derived from K selected  
4 waveforms,  
5 wherein said modulating means further includes an in-phase path and a  
6 quadrature path coupled to one another so that simultaneously transmitting the two  
7 intermediate composite waveforms respectively through the in-phase path and the  
8 quadrature path produces an in-phase modulated waveform and a quadrature  
9 modulated waveform, the two modulated waveforms being 90° out of phase with  
10 respect to one another; and  
11 further including means for combining the in-phase modulated waveform and

12 the quadrature modulated waveform so as to produce a quadrature phase modulated  
13 carrier signal.

1 21. A data communications system according to claim 18, wherein the  
2 intermediate waveform from said in-phase path is encoded with a first spreading  
3 function, and the intermediate waveform from the quadrature path is encoded with a  
4 second spreading function.

1 22. A data communications system according to claim 18, further  
2 including means for selectively inverting each of said component waveforms so as to  
3 create a larger set of composite waveforms.

1 23. A data communications system according to claim 17, wherein further  
2 including means for selectively inverting each of said component waveforms so as to  
3 create a larger set of composite waveforms.

1 24. A data communications system according to claim 23, wherein the  
2 means for selectively inverting each of said component waveforms includes means  
3 for selectively modulating each of said component waveforms using PSK techniques.

1 25. A data communications system according to claim 23, wherein the  
2 means for selectively inverting each of said component waveforms includes means  
3 for selectively modulating each of said component waveforms using DPSK  
4 techniques.

1 26. A data communications system according to claim 18, wherein said  
2 set of said plurality of waveforms includes Walsh functions.

1 27. A data communications system according to claim 18, wherein  $n$  and  
2  $m$  each equal 4 so that said set of  $M$  waveforms includes four subsets, each having  
3 four of said Walsh functions.

1           28.    A data communications system according to claim 17, wherein said  
2   processing means includes means for summing contemporaneous portions of K  
3   selected waveforms, so as to produce a composite waveform having only two distinct  
4   amplitude levels.

1           29.    A data communications system according to claim 17, wherein said  
2   processing means includes means for summing contemporaneous portions of K  
3   selected waveforms, so as to produce a composite waveform having at least three  
4   distinct amplitude levels.

1           30.    A data communications system according to claim 17, wherein said  
2   processing means includes means for encoding said composite waveform with a  
3   spreading function.

1           31.    A data communications system according to claim 17, wherein said  
2   processing means includes means for encoding each of said K selected waveforms  
3   with a spreading function, so as to produce K spread waveforms, prior to producing  
4   said composite waveform.

1           32.    A data transmission system according to claim 17, further including  
2           modulating means for modulating a carrier signal as a function of said  
3   composite waveform so as to produce a modulated carrier composite signal and  
4   transmission means for transmitting said modulated carrier composite signal through  
5   said transmission medium;

6           receiver means for receiving said modulated carrier composite signal so as to  
7   produce a received carrier signal;

8           demodulation means for demodulating said received carrier signal so as to  
9   reproduce said composite waveform;

10          decomposition means for decomposing said composite signal in order to  
11   reproduce K received component waveforms corresponding to said K selected  
12   waveforms; and

13 means for reproducing the input data symbol as a function of said K selected  
14 waveforms.

1 33. A data communications system according to claim 32, wherein said  
2 demodulation means includes an in-phase demodulation path and a quadrature  
3 demodulation path.

1 34. A data communications system according to claim 30, wherein said  
2 demodulation means further includes means for stripping a spreading function from  
3 said composite waveform in said in-phase demodulation path and from said  
4 composite waveform in said quadrature demodulation path.

1 35. A data communications system according to claim 32, wherein said  
2 decomposition means includes means for correlating said composite waveform  
3 against all of said component waveforms from said subsets so as to produce a highest  
4 correlation result from each subset, and selecting a correlated component waveform  
5 corresponding to said highest correlation result from each of said n subsets so as to  
6 produce K correlated component waveforms, wherein said produced K correlated  
7 component waveforms are representative of a corresponding one of said data  
8 symbols.

1 36. A data communications system according to claim 35, wherein said  
2 decomposition means further includes means for detecting inverted waveforms.

1 37. A data communications system for receiving data symbols transferred  
2 as predefined composite waveforms,

3 wherein each composite waveform is derived, at least in part, as a function of:

- 4 (A) selecting K waveforms from a set of M mutually  
5 orthogonal component waveforms so as to produce K selected  
6 waveforms for each of said data symbols, wherein  $2 \leq K \leq M-1$ ; and  
7 (B) processing contemporaneous portions of said K selected

8 waveforms so as to produce, at least in part, the composite waveform  
9 representative of the symbol, and  
10 said composite waveform is used to modulate a carrier signal  
11 so as to produce a modulated carrier composite signal for transmitting  
12 the composite waveform through the transmission medium;  
13 said system comprising:  
14 demodulation means for demodulating said modulated carrier composite  
15 signal so as to reproduce said composite waveform;  
16 decomposition means for decomposing said composite signal in order to  
17 reproduce K received waveforms; and  
18 means for reproducing said data symbols as a function of said reproduced K  
19 received waveforms.

1 38. A data communications system according to claim 37, wherein each of  
2 said data symbols is represented, at least in part, as a composite waveform derived, at  
3 least in part, as a function of:

4 (A) selecting at least one waveform from each subset of n subsets of  
5 said component waveforms, wherein each subset includes m component  
6 waveforms, so as to produce K selected component waveforms; and  
7 (B) processing contemporaneous portions of said K selected  
8 representative of at least a part of said symbol.

1 39. A data communications system according to claim 37, wherein said  
2 composite waveform is derived from two intermediate composite waveforms, one  
3 modulated in an in-phase path so as to provide an in-phase modulated signal and the  
4 other modulated in a quadrature path so as to provide a quadrature modulated signal,  
5 wherein said demodulation means includes an in-phase demodulation path for  
6 demodulating the in-phase modulated signal so as to provide an in-phase  
7 demodulated composite waveform, and a quadrature demodulation path for  
8 demodulating the quadrature modulated signal so as to provide a quadrature  
9 demodulated composite waveform.

1           40.    A data communications system according to claim 37, wherein said  
2 demodulation means further includes means for stripping a spreading function from  
3 an in-phase demodulated composite waveform from the quadrature demodulated  
4 composite waveform.

1           41.    A data communications system according to claim 38, wherein said  
2 decomposition means includes means for correlating said composite waveform  
3 against all of said waveforms from said subsets so as to produce a highest correlation  
4 result from each subset, and selecting a correlated waveform corresponding to said  
5 highest correlation result from each of said n subsets so as to produce K correlated  
6 waveforms being representative of a corresponding one of said data symbols.

1           42.    A data communications system according to claim 38, wherein said  
2 decomposition means further includes means for detecting inverted waveforms.

1           43.    A method of transferring data as composite waveforms representing  
2 predefined input data symbols, comprising:

- 3           A.    receiving digital data as data symbols;  
4           B.    selecting, as a function of each data symbol K selected waveforms  
5 from a set of M mutually orthogonal component waveforms, said selected waveforms  
6 being representative of said data symbol;  
7           C.    processing contemporaneous portions of said K selected waveforms so  
8 as to produce a composite waveform; and  
9           D.    modulating a carrier signal as a function of said composite waveform  
10 so as to produce a modulated carrier signal and transmitting said modulated carrier  
11 signal.

1           44.    A method according to claim 43, wherein

2           B1. said step of selecting includes the step of selecting, as a function of each  
3 data symbol, at least one waveform from each of n subsets of m component  
4 waveforms so as to provide K selected waveforms, said selected waveforms being



5 representative at least a part of said data symbol; and  
6 C1. said step of processing includes the step of processing  
7 contemporaneous portions of said K selected component waveforms so as to produce  
8 the composite waveform.

1 45. A method according to claim 44, further including:

2 E. receiving said modulated carrier signal so as to produce a received  
3 carrier signal;

4 F. demodulating said received carrier signal so as to reproduce said  
5 composite signal;

6 G. decompositioning said composite signal in order to reproduce said K  
7 selected waveforms; and

8 H. reproducing said data symbols as a function of the reproduced K  
9 selected waveforms.

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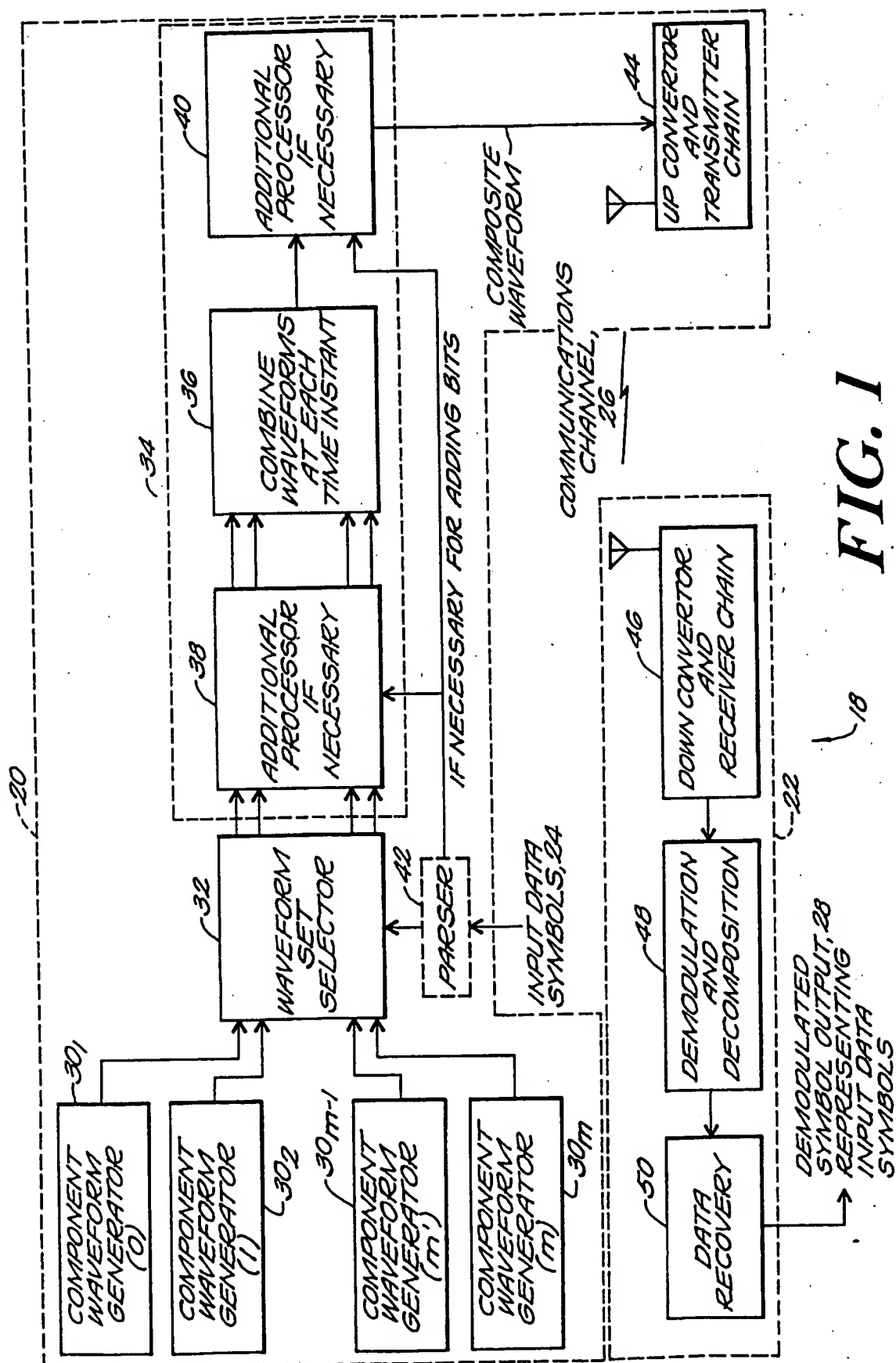
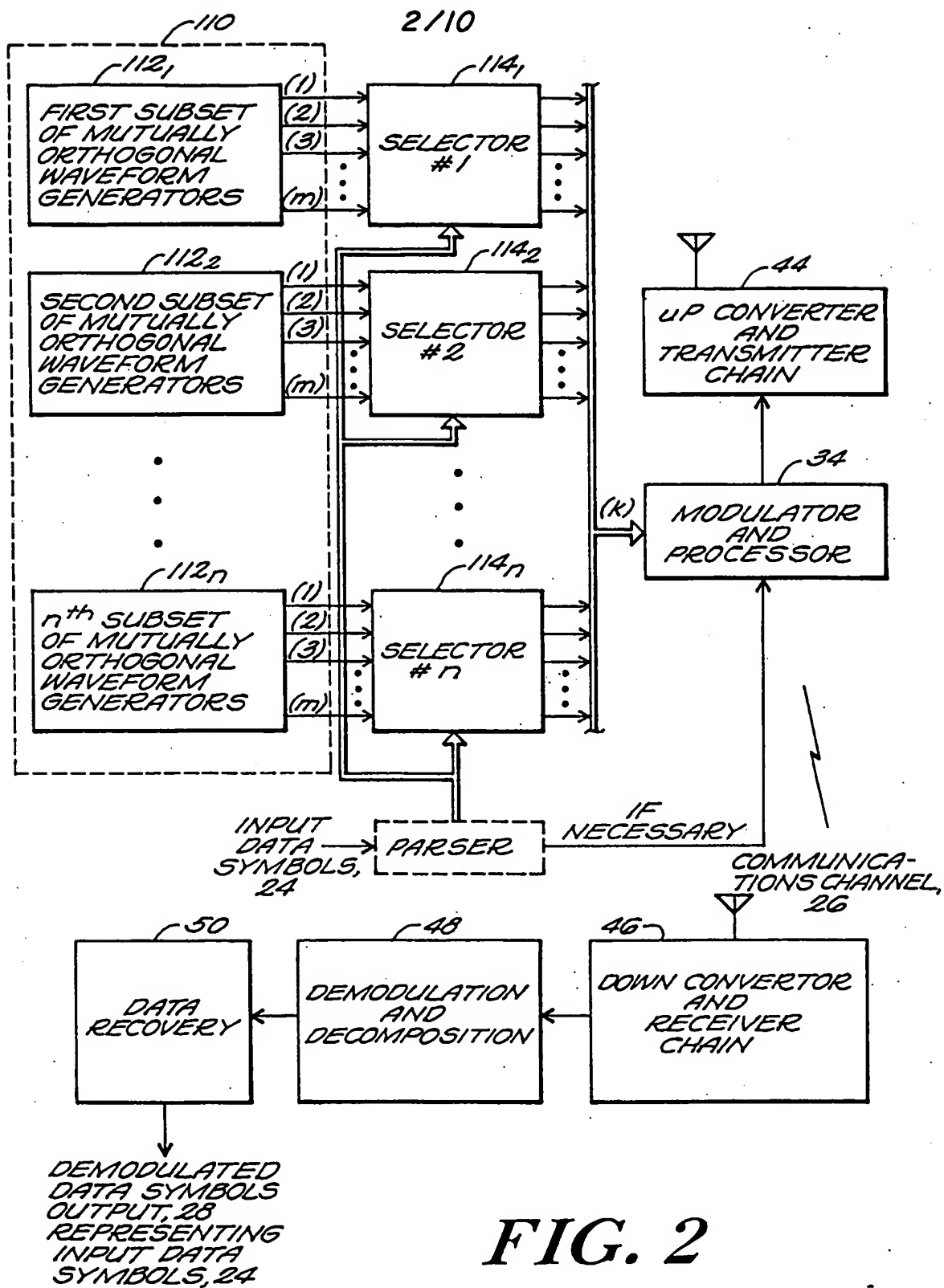


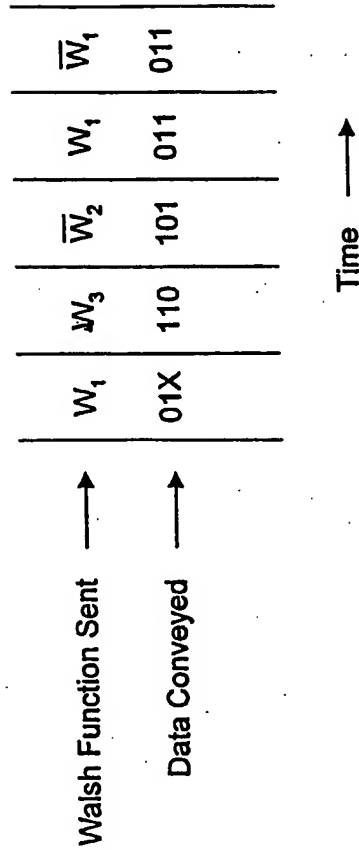
FIG. 1



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$W_n$  = Walsh Function #n  
 $\overline{W}_n$  = Inverted Walsh Function #n

SUBGROUP	
$W_0$	$W_1$
$W_2$	$W_3$
---	---
$\overline{W}_0$	$\overline{W}_1$
$\overline{W}_2$	$\overline{W}_3$



Data Associated With  
Walsh Functions:

$W_0$  or  $\overline{W}_0$  = 00

$W_1$  or  $\overline{W}_1$  = 01

$W_2$  or  $\overline{W}_2$  = 10

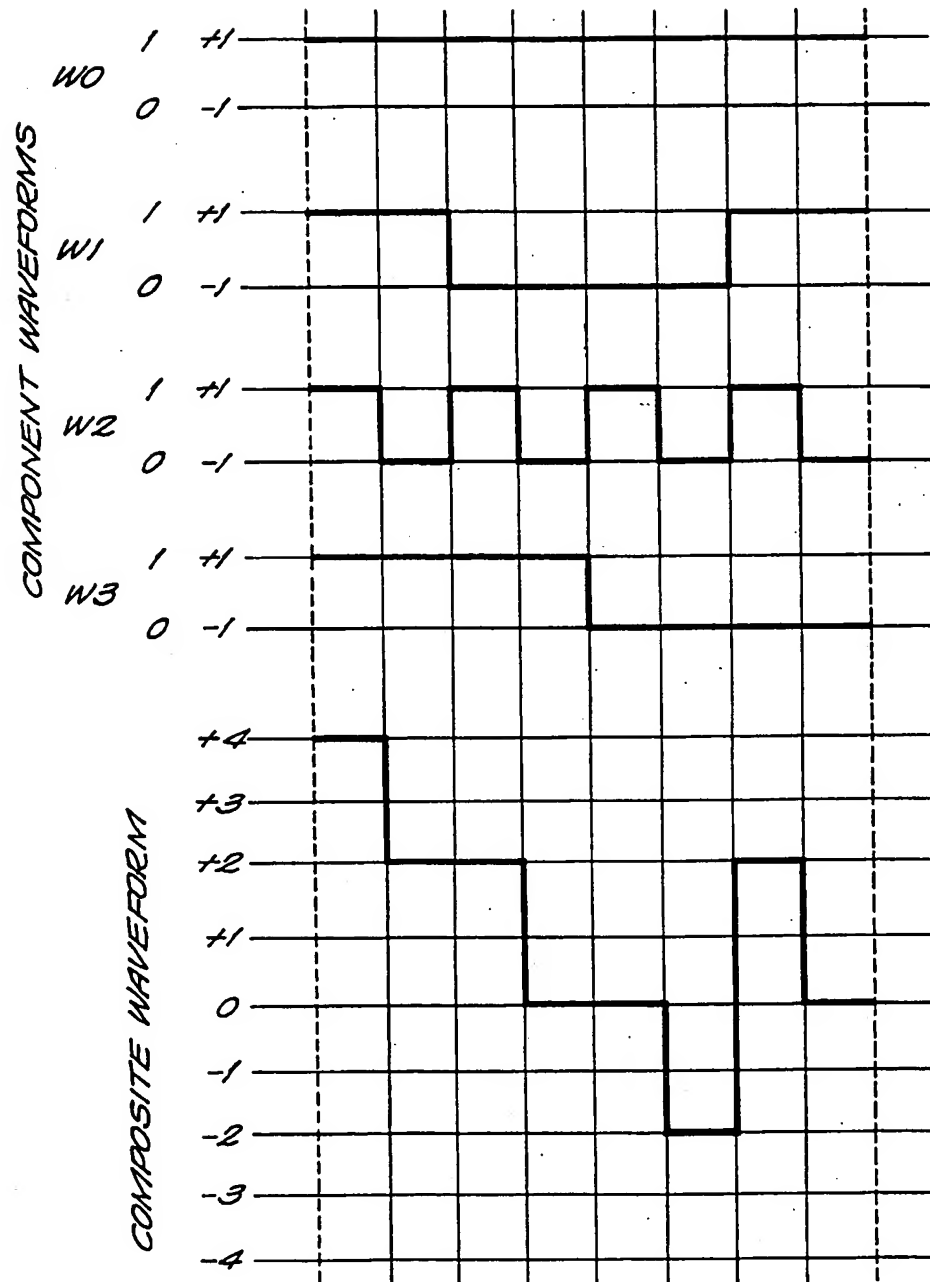
$W_3$  or  $\overline{W}_3$  = 11

Adjacent Set Same Polarity = 0

Adjacent Set Different Polarity = 1

FIG. 3

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**FIG. 4**

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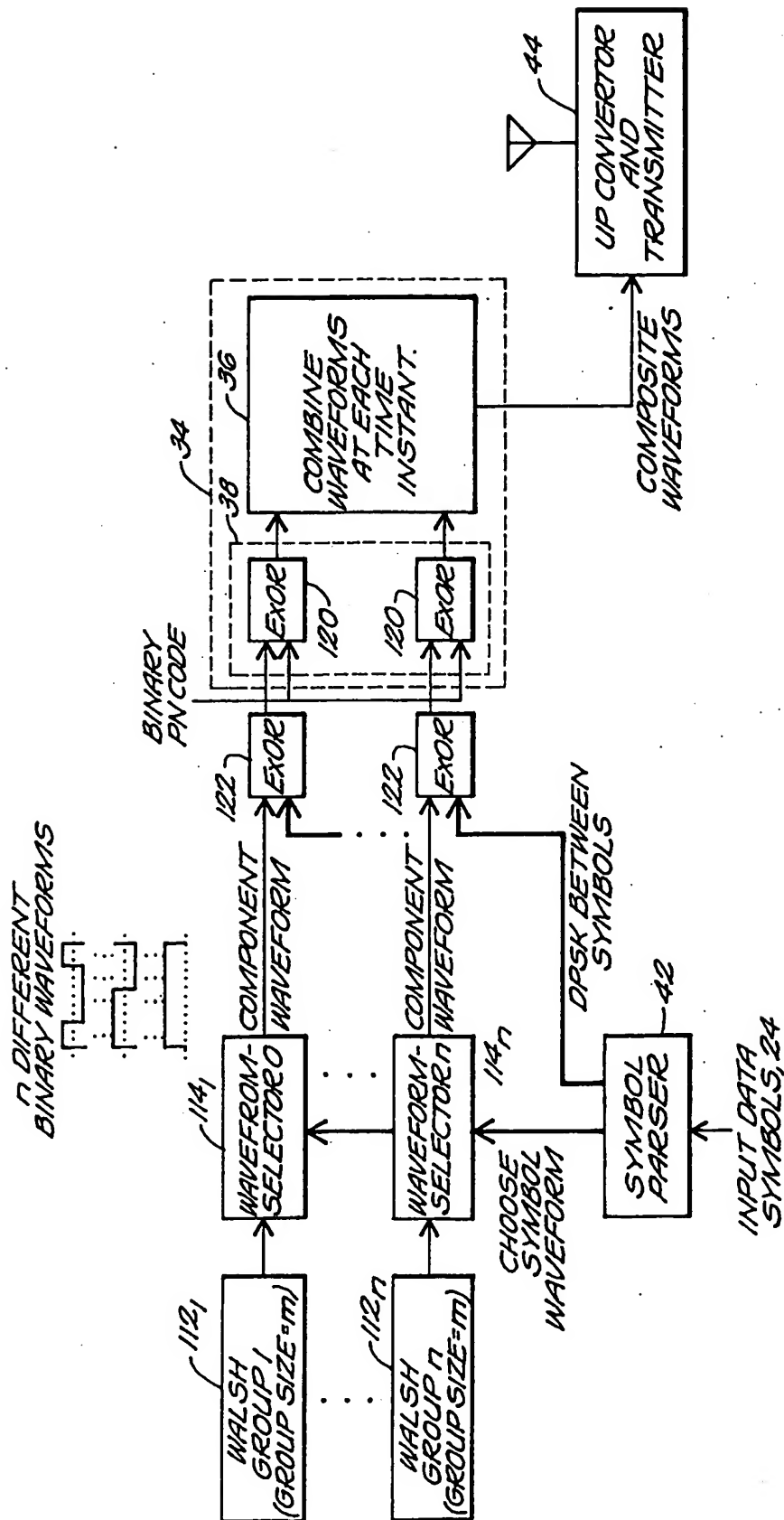
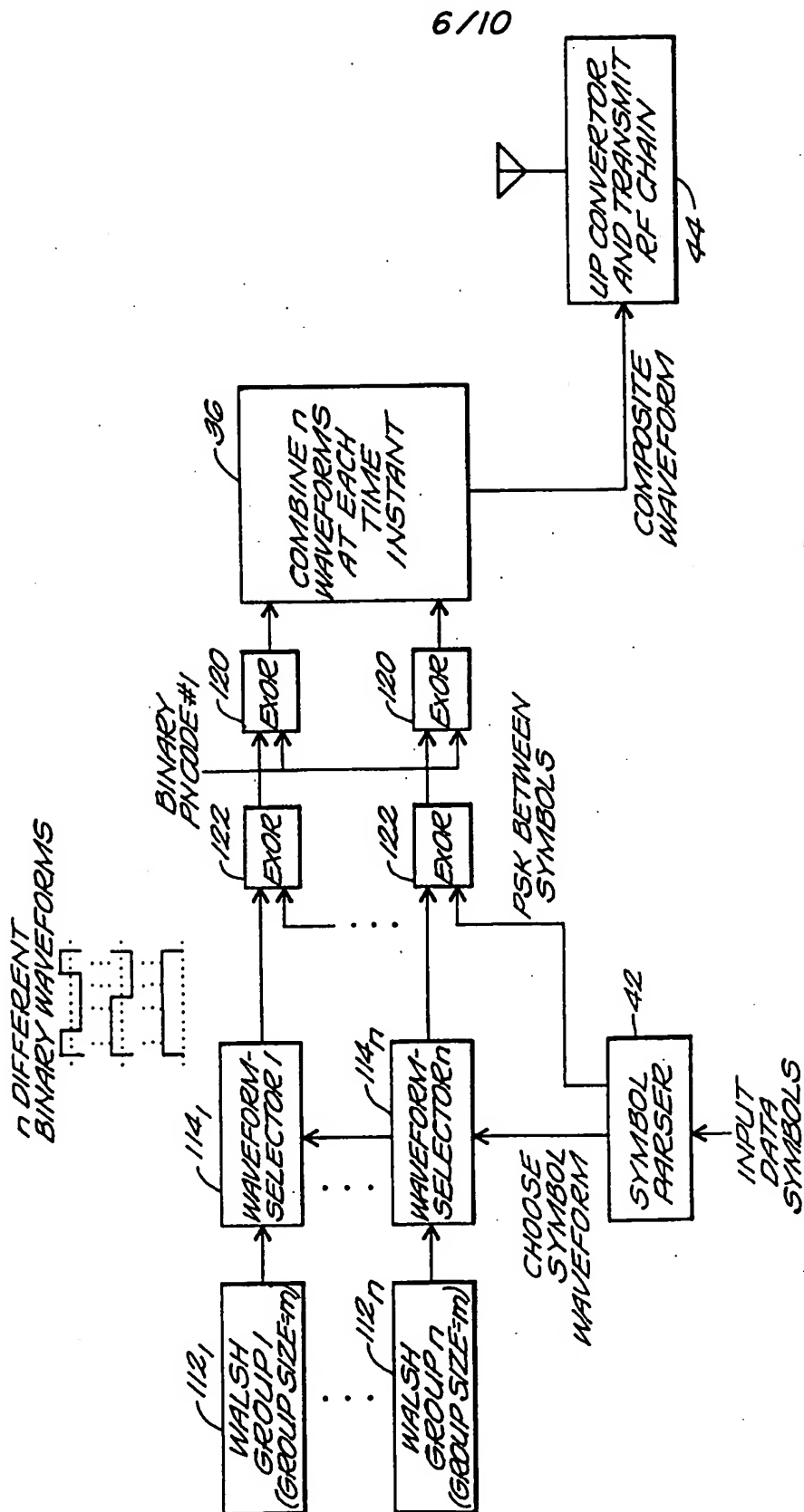


FIG. 5



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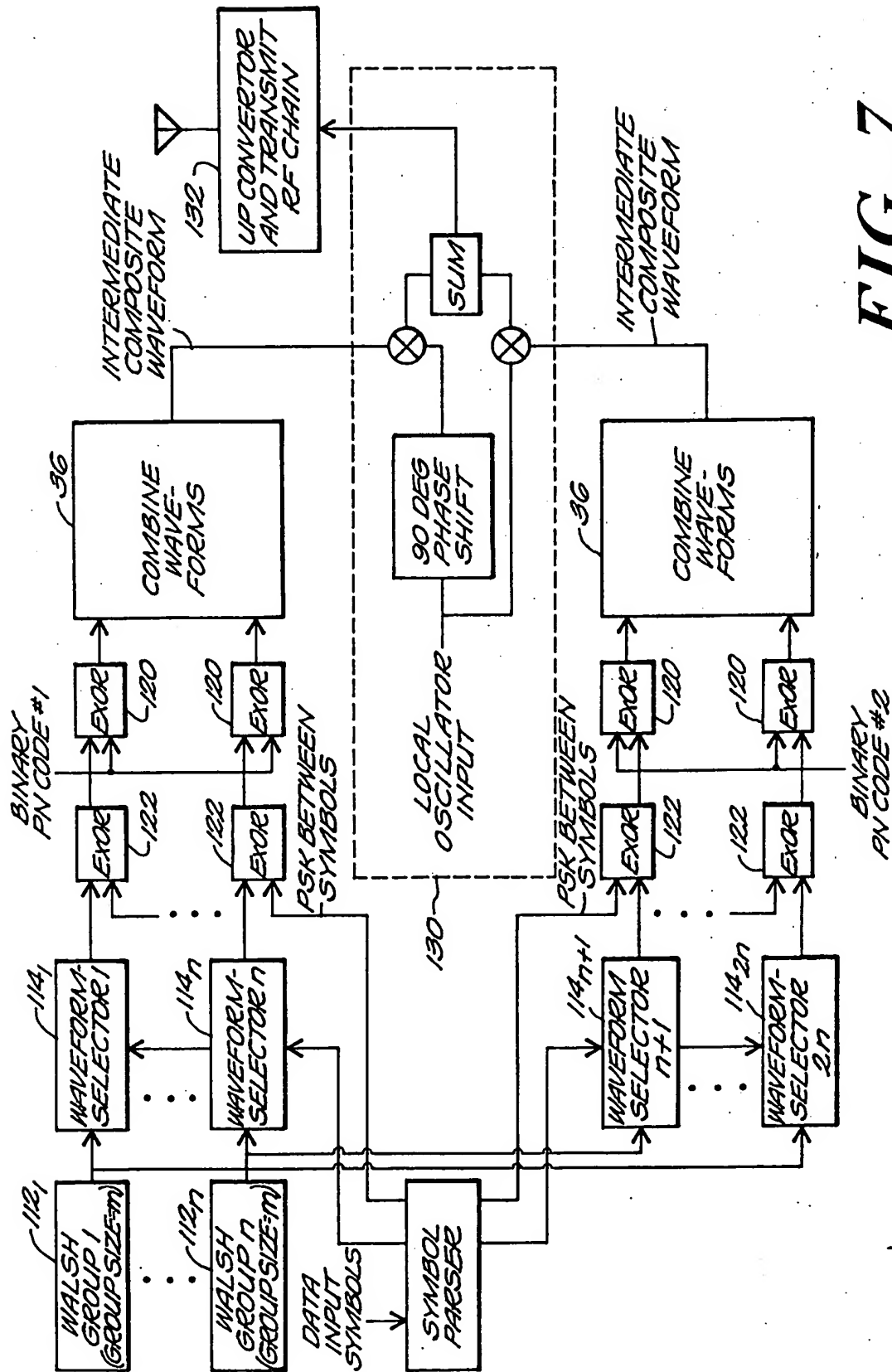


FIG. 7



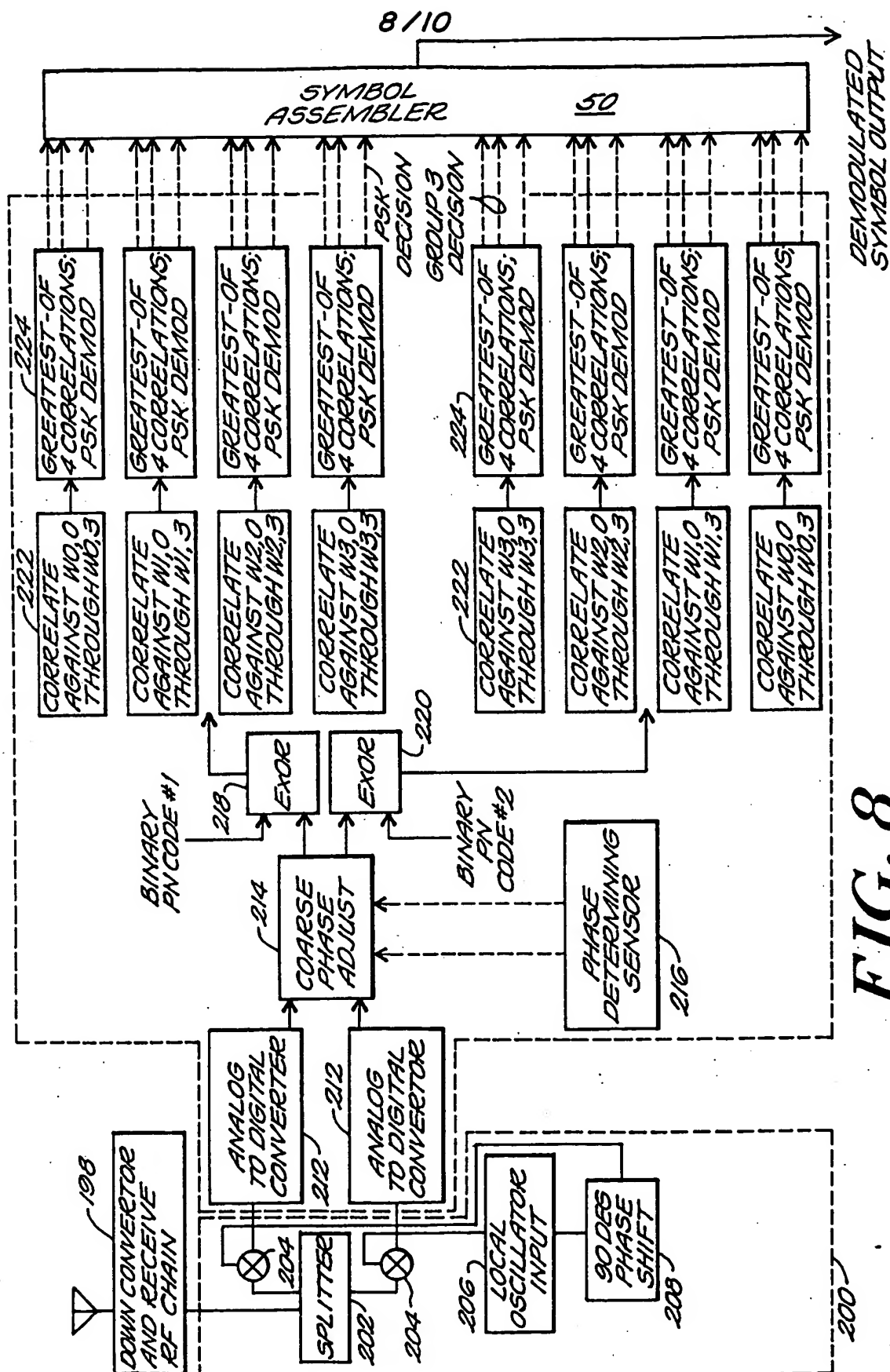


FIG. 8

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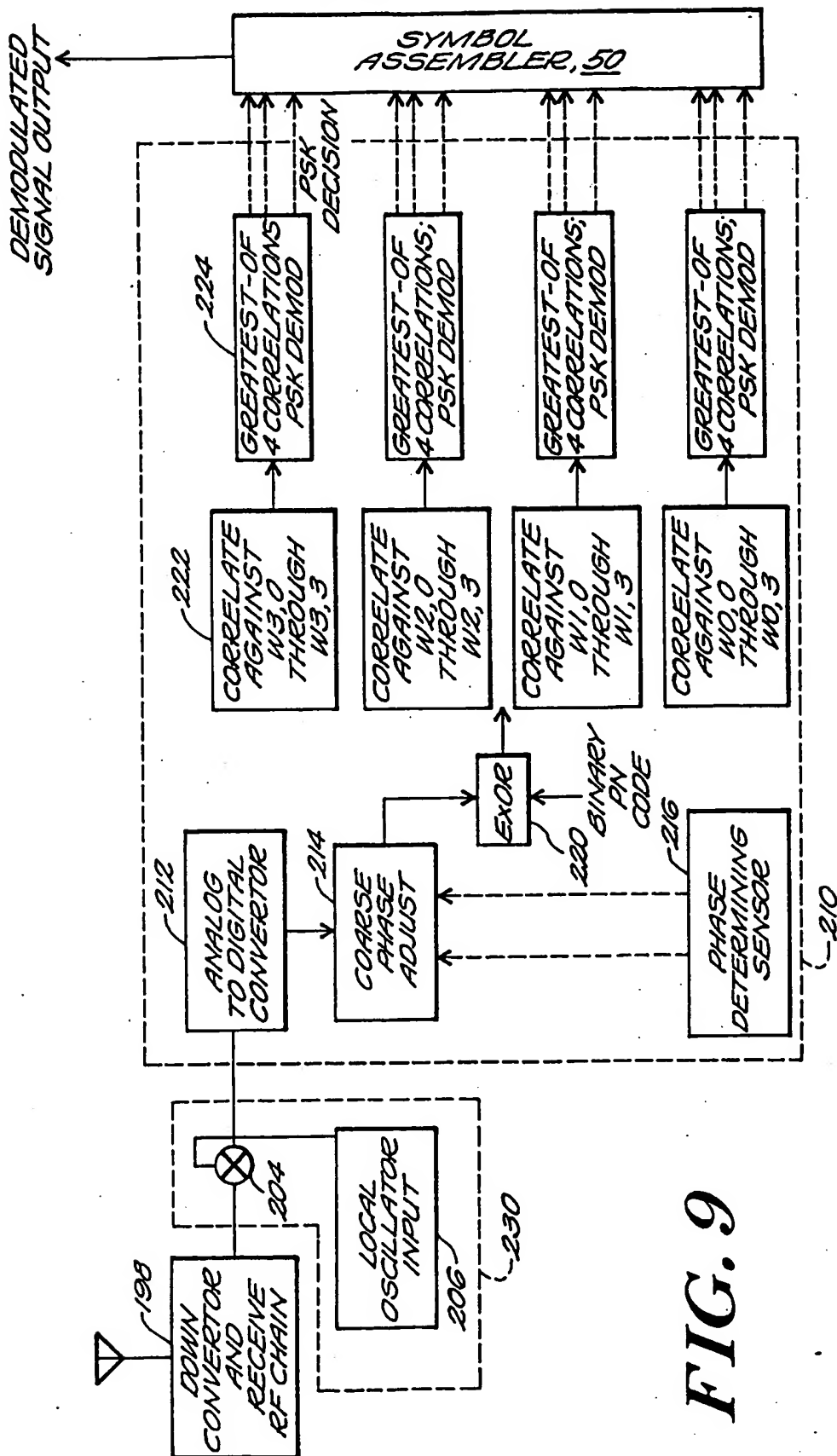


FIG. 9

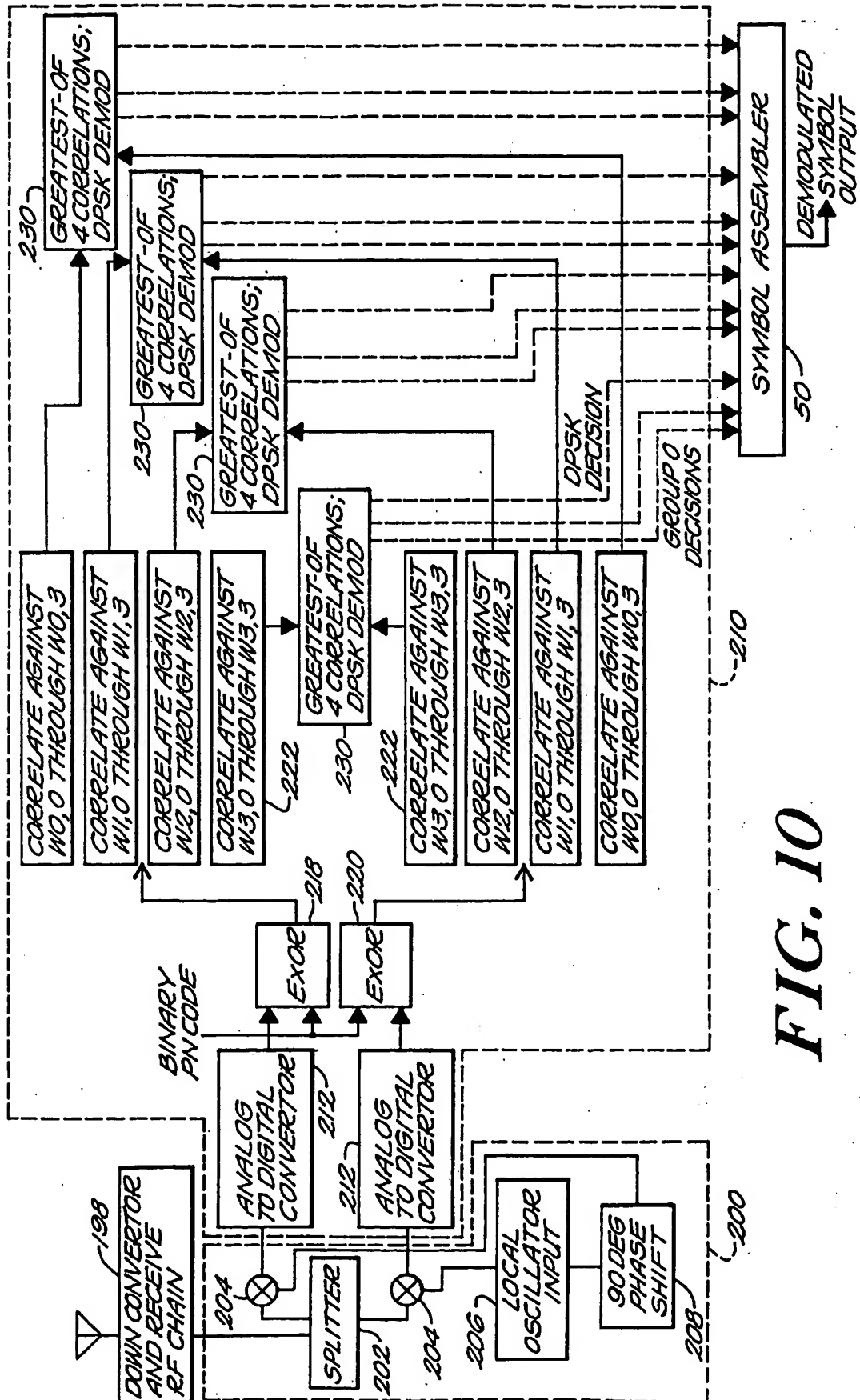


FIG. 10

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US98/12913**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(6) : H04B 1/69; H04L 27/00, 27/20

US CL : 375/200, 259, 308; 370/209

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 375/200, 208, 209, 210, 259, 295, 308; 370/209

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A,P	US 5,745,525 A (HUNSINGER et al) 28 April 1998, abstract, col. 2, lines 17-34, col. 3, line 63 to col. 4, line 19.	1-45
A	US 5,029,184 A (ANDREN et al) 02 July 1991, figs. 2 and 5, col. 3, line 46 to col. 4, line 7, col. 9, lines 36-57 and col. 10, lines 11-31.	1-45
A	US 4,403,331 A (HALPERN et al) 06 September 1983, abstract, col. 4, lines 53-66 and col. 6, line 34 to col. 7, line 22.	1-45
A	US 3,697,697 A (AUDRETSCH, JR. et al) 10 October 1972, fig. 1, col. 4, lines 26-42 and col. 6, lines 7-14.	1-45

☐ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

* Special categories of cited documents:	"I" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Z" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

11 SEPTEMBER 1998

Date of mailing of the international search report

15 OCT 1998

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